

**ANALYSIS OF PV WIND BATTERY HYBRID
POWER SYSTEM (PWBHPS) USING SIMPLE
ZONE PROBABILITIES (SZP) METHOD FOR
HOUSEHOLD IN MALAYSIA**

SURIADI

UNIVERSITI SAINS MALAYSIA

2016

**ANALYSIS OF PV WIND BATTERY HYBRID POWER SYSTEM (PWBHPS)
USING SIMPLE ZONE PROBABILITIES (SZP) METHOD FOR
HOUSEHOLD IN MALAYSIA**

By

SURIADI

**Thesis submitted in fulfillment of the
requirements for the degree
of Doctor of Philosophy**

November 2016

ACKNOWLEDGEMENTS

First and foremost, I am highly gratefulness and indebted to Allah Subhanahu Wata'ala the Almighty for providing me peace of mind, ability and perseverance accomplishing my research. My foremost thanks go to my father, for his love and encouragement.

I would like to thank to my supervisor Asc.Prof. Dr. Soib Taib for his guidance and support throughout this project.

Peace and overwhelming grace be upon my late mother Dahniar binti Abdulrahman. She had inspired me to strive for excellence. May Allah bestow her with Al Firdaus.

I would also thank to the government of Province Aceh, Indonesia and Finance Ministry through Board of Development Education Fund (LPDP-Indonesia) for their research funding and facilities.

My thanks are also to the Dean of School of Electrical and Electronic Engineering, Prof. Dr. Mohd Rizal Arshad, for their endless encouragement and support during my study.

Deserve my gratitude to the lectures, administration and technician of School of Electrical and Electronic Engineering for their help and motivational support. My special thanks to the Power Lab staff; Ahmad Shaukhi bin Noor, Jamaludin Che Amat, Nazir bin Abdullah and Hairul Nizam bin Abdul Rahman.

I would like to thank my lovely wife Imelda Chaidir and my beloved children; M. Harris Danial and Sarah Miralda for their unflinching support and for being patiently supporting my carrier in life.

Also I will never forget to be thankful to all my brothers and sisters, for their caring and do'a to Almighty Allah. My thanks are also to my friend and colleagues in power lab research group namely Shawal bin Jadin, Tiang Tow Leong, Faizal bin Abdullah and all for their assistance and affection.

Suriadi bin M. Ali

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xvi
ABSTRAK	xx
ABSTRACT	xxii
CHAPTER ONE: INTRODUCTION	
1.1 Introduction	1
1.2 Problem Statement	4
1.3 Research Objectives	7
1.4 Scope of Research	7
1.5 Research Approach	8
1.6 Outline of Thesis	8
CHAPTER TWO: LITERATURE REVIEW	
2.1 Introduction	10
2.2 Hybrid Power System Technology	11
2.3 Technical Configurations for HPS	18
2.3.1 DC-Coupled Systems	18
2.3.2 AC-Coupled Systems	19
2.4 Solar Cell	21

2.4.1	Solar Irradiance	22
2.4.2	Photovoltaic System	23
2.4.3	Solar Cell Performance	24
2.4.4	Modeling of Solar Cell	24
2.4.5	PV array Characteristic Curve	27
2.5	Wind Turbine	28
2.5.1	Modern Wind Turbine Design	29
2.5.2	Wind Power and Speed	32
2.5.3	Wind Power Generation	33
2.5.4	Rotor Swept Area	34
2.5.5	Wind Speed Extrapolation	35
2.5.6	Wind Energy Output from Wind Turbine	35
2.6	Charge controller	36
2.7	Inverter	36
2.8	Battery Storage	37
2.9	Previous PV- Wind Hybrid System Modeling	38
2.10	Economic Analysis of PWBHPS	39
2.10.1	Cost of the System	39
2.10.2	Life Cycle Cost	40
2.10.3	Electrical Cost	41
2.10.4	Payback Period	42
2.11	Summary	42

CHAPTER THREE: METHODOLOGY

3.1.	Introduction	43
3.2	Development of PV-Wind Battery Hybrid Power System	44

3.3	Solar PV Panel	48
3.4	Wind Turbine	52
3.5	Hybrid Controller	54
3.5.1	Rectifier	55
3.5.2	Buck Converter	56
3.5.3	Dump Load	58
3.6	Inverter	59
3.7	Battery	62
3.8	Switch Controller	63
3.9	SZP Algorithm	67
3.9.1	Concept of SZP	67
3.9.2	SZP Algorithm	69
3.10	Summary	73

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1	Introduction	74
4.2	Solar Power Source in Malaysia	76
4.3	Wind Power Source in Malaysia	77
4.4	Performance of Switch Controller Device.	83
4.5	Output Inverter	85
4.6	Input and Output of PWBHPS based on USM engineering Campus data	86
4.6.1	PWBHPS Energy Input	88
4.6.2	PWBHPS Energy Output	90
4.6.3.	PWBHPS Operation for Load 200 W	93
4.6.4.	PWBHPS Operation for Load 300 W	98

4.6.5.	PWBHPS Operation for Load 500 W	102
4.6.6.	PWBHPS Operation for Load 600 W	106
4.7	PWBHPS Analysis at Taman Seri Aceh	112
4.7.1	PWBHPS at Wind Hub Height 10 meter	112
4.7.2	PWBHPS at Wind Hub Height 30 meter	114
4.7.3	PWBHPS at Wind Hub Height 50 meter	116
4.8	PWBHPS Analysis at Selected Location in Peninsular Malaysia Using SZP method	120
4.8.1	Mersing	120
4.8.2	Kuala Terengganu	122
4.8.3	Johor Baharu	123
4.8.4	Kuantan	125
4.8.5	Kota Bharu	127
4.8.6	Langkawi	128
4.8.7	Alor Setar	130
4.8.8	Ipoh	132
4.8.9	Penang	133
4.9	PWBHPS Analysis at Selected Location in Peninsular Malaysia without Using SZP method	135
4.9.1	Mersing	135
4.9.2	Kuala Terengganu	137
4.9.3	Johor Baharu	139
4.9.4	Kuantan	141
4.9.5	Kota Bharu	142
4.9.6	Langkawi	144
4.9.7	Alor Setar	145

4.9.8	Ipoh	146
4.9.9	Penang	148
4.10	Economic Analysis	150
4.11	Summary	155

CHAPTER FIVE: CONCLUSIONS

5.1	Conclusions	156
5.2	Research Contribution	158
5.3	Future work	158

REFERENCES	160
-------------------	-----

APPENDICES

Appendix A	PICBASIC PRO
Appendix B	Solar Module Datasheet
Appendix C	Wind System Data Sheet
Appendix D	IC HPCL-3120 Data Sheet
Appendix E	IC TL 494 Data Sheet
Appendix F	ACS 712 Sensor
Appendix G	Sinusoidal Inverter

LIST OF PUBLICATIONS

LIST OF TABLES

	Page
Table 3.1	SPM-100-M Solar module specification 49
Table 3.2	Technical data of the TR-2kW wind turbine 53
Table 3.3	The operating recommendation of IC HCPL-3120 60
Table 4. 1	Household load data consumption 75
Table 4.2	The various loads operation performance 91
Table 4. 3	SOC condition for various loads (21/9/2015) 92
Table 4.4	SOC condition to supply 200 W load (3/4/2015) 96
Table 4.5	SOC condition to supply 300 W load (4/4/2015) 100
Table 4.6	SOC condition for 500 W load (5/4/2015) 104
Table 4.7	SOC condition to supply 600 W load (6/4/2015) 108
Table 4.8	Comparison power time length of load operation between experiment and calculation 111
Table 4.9	PWBHPS power output by wind hub height 10 meter 113
Table 4. 10	PWBHPS power output by wind hub height 30 meter 115
Table 4.11	PWBHPS power output by wind hub height 50 meter 118
Table 4.12	PV-wind hybrid power output in Taman Seri Acheh at 10, 30 and 50 meter wind hub height (7 April 2015) 118
Table 4.13	PWBHPS power output at Mersing 120
Table 4.14	PWBHPS power output at Kuala Terengganu 123
Table 4.15	PWBHPS power output at Johor Baharu 124
Table 4.16	PWBHPS power output at Kuantan 126
Table 4.17	PWBHPS power output at Kota Bharu 127
Table 4.18	PWBHPS power output at Langkawi 129
Table 4.19	PWBHPS power output at Alor Setar 131
Table 4. 20	PWBHPS power output at Ipoh 132

Table 4. 21	PWBHPS power output at Penang	134
Table 4. 22	PWBHPS power output without SZP method at Mersing	136
Table 4. 23	PWBHPS power output without SZP method at Kuala Terengganu	138
Table 4. 24	PWBHPS power output without SZP method at Johor Baharu	140
Table 4. 25	PWBHPS power output without SZP method at Kuantan	141
Table 4. 26	PWBHPS power output without SZP method at Kota Bharu	143
Table 4. 27	PWBHPS power output without SZP method at Langkawi	144
Table 4. 28	PWBHPS power output without SZP method at Alor Setar	146
Table 4. 29	PWBHPS power output without SZP method at Ipoh	147
Table 4. 30	PWBHPS power output without SZP method at Penang	148
Table 4. 31	Comparison of PWBHPS Percentage using SZP and without SZP to serve the load at selected location in Peninsular Malaysia	149

LIST OF FIGURES

	Page
Figure 2. 1 DC-coupled hybrid energy system topology	19
Figure 2. 2 Topology of PFAC coupled hybrid energy system	20
Figure 2. 3 Topology of HFAC coupled systems	21
Figure 2.4 Terrestrial solar spectrum (Arizona Solar Power Society, 2008)	23
Figure 2. 5 Irradiance effect on electrical characteristic	28
Figure 2.6 Temperature effect on electrical characteristic	28
Figure 2.7 Wind turbine model (a) Vertical axis and (b) Horizontal axis	29
Figure 2.8 HAWT rotor configuration (a) Upwind (b) Downwind	30
Figure 2. 9 Parts of wind turbines	32
Figure 2. 10 PV wind hybrid operational region (Darbyshire, 2010)	39
Figure 3.1 Block diagram of PWBHPS design	43
Figure 3.2 Flow chart of the PWBHPS process	45
Figure 3. 3 chart of the charging mode operation	46
Figure 3. 4 Flowchart of the discharging mode operation	47
Figure 3.5 Solar panel constructions	48
Figure 3.6 V-I characteristic	50
Figure 3.7 PV characteristic	51
Figure 3.8 WeatherLink data logger sensors	52
Figure 3.9 TR-2kW wind turbine	52
Figure 3.10 Model wind turbine TR-2kW output power versus wind speed	53
Figure 3.11 Hybrid controller circuit	54
Figure 3.12 Three phase full bridge diode rectifier	55
Figure 3. 13 Bulk converter	57
Figure 3.14 Component of hybrid controller	58

Figure 3.15	Single phase inverter circuit	59
Figure 3.16	MOSFET driving circuit	60
Figure 3.17	Inverter Control Circuit	61
Figure 3.18	Inverter configuration	62
Figure 3.19	Battery storage	63
Figure 3.20	Flow chart of switch controller	64
Figure 3. 21	Switch Controller Circuit	66
Figure 3.22	Switch controller device	67
Figure 3.23	Power of PV wind hybrid and load	68
Figure 3.24	Different power between PV-wind hybrid with load	68
Figure 3.25	Time zone of operation	70
Figure 4.1	The area of PV/Wind/Battery hybrid station	74
Figure 4.2	Load profile for a household at Taman Ilmu, Nibong Tebal, Penang	76
Figure 4.3	Monthly average solar radiation (Samsudin, 1999)	77
Figure 4.4	Hourly wind speed in Johor Baharu for month of January 2015	78
Figure 4.5	Hourly wind speed in Langkawi for month of January 2015	79
Figure 4.6	Hourly wind speed in Kota Bharu	79
Figure 4.7	Hourly wind speed in Penang	80
Figure 4.8	Hourly wind speed in Kuala Terengganu	81
Figure 4.9	Hourly wind speed in Kuantan	81
Figure 4.10	Hourly wind speed in Ipoh	82
Figure 4.11	Hourly wind speed in Mersing	82
Figure 4.12	Hourly wind speed in Alor Setar	83
Figure 4.13	Voltage and current input inverter	84
Figure 4. 14	Auto change switch of PWBHPS to grid	85

Figure 4. 15	Auto change switch of grid to PWBHPS	86
Figure 4.16	PV solar power source	88
Figure 4.17	Wind power source	88
Figure 4.18	Hybrid controller output power source	89
Figure 4.19	Charge and discharge battery power source	89
Figure 4.20	The results of PWBHPS performance implementation in USM Engineering Campus	90
Figure 4.21	Time length of PV wind hybrid power output for 200 W load.	93
Figure 4.22	Solar insolation (3 April 2015)	94
Figure 4. 23	Daily wind speed (3 April 2015)	95
Figure 4.24	Daily PV wind hybrid power output for 200 W load (3 April 2015).	97
Figure 4.25	Time length of PV wind hybrid power output for 300 W load.	98
Figure 4.26	Solar insolation (4 April 2015)	99
Figure 4.27	Daily wind speed (4 April 2015)	99
Figure 4.28	Daily PV wind hybrid power output for 300 W laod (4 April 2015)	101
Figure 4.29	Time length of PV wind hybrid power output for 500 Watt load	102
Figure 4.30	Solar insolation (5 April 2015)	103
Figure 4.31	Daily wind speed (5 April 2015)	103
Figure 4.32	Daily PV wind hybrid power output for 500 W load (5 April 2015)	105
Figure 4.33	Time length of PV wind hybrid power output for 600 Watt load	106
Figure 4.34	Solar insolation (6 April 2015)	107
Figure 4.35	Daily wind speed (6 April 2015)	107
Figure 4.36	Daily PV wind hybrid power output for 600 W load (6 April 2015)	109
Figure 4.37	Daily power output at 10 meter hub height (7 April 2015)	113

Figure 4. 38	Daily output power at 30 meter hub height (7 April 2015)	115
Figure 4. 39	Daily output power at 50 meter hub height (7 April 2015)	117
Figure 4.40	PV wind hybrid power output in Mersing	120
Figure 4.41	PV wind hybrid power output in Kuala Terengganu	122
Figure 4. 42	PV wind hybrid power output in Johor Baharu	124
Figure 4. 43	PV wind hybrid power output in Kuantan	125
Figure 4. 44	PV wind hybrid power output in Kota Bharu	127
Figure 4. 45	PV wind hybrid power output in Langkawi	129
Figure 4. 46	PV wind hybrid power output in Alor Setar	130
Figure 4. 47	PV wind hybrid power output in Ipoh	132
Figure 4. 48	PV wind hybrid power output in Penang	133
Figure 4. 49	PV wind hybrid power output in Mersing without SZP method	135
Figure 4. 50	PV wind hybrid power output in Kuala Terengganu without SZP method	138
Figure 4. 51	PV wind hybrid power output in Johor Baharu without SZP method	139
Figure 4. 52	PV wind hybrid power output in Kuantan without SZP method	141
Figure 4. 53	PV wind hybrid power output in Kota Bharu without SZP method	142
Figure 4. 54	PV wind hybrid power output in Langkawi without SZP method	144
Figure 4. 55	PV wind hybrid power output in Alor Setar without SZP method	145
Figure 4. 56	PV wind hybrid power output in Ipoh without SZP method	147
Figure 4. 57	PV wind hybrid power output in Penang without SZP method	148
Figure 4. 58	Chart of PWBHPS output Power	150

LIST OF ABBREVIATIONS

AC	Alternating Current
AH	Ampere Hour
AM	Air Mass
DC	Direct Current
DG	Diesel Generator
DOD	Depth Of Discharge
EEQ	Electrical Energy Quantities
HAWT	Horizontal Axis Wind Turbine
HOMER	Homer Energy
HPS	Hybrid Power System
HRES	Hybrid Renewable Energy System
LCC	Life Cycle Cost
MNEP	Malaysia's National Energy Policy
MSC	Meteorological Service of Canada
NC	Normally Close
NO	Normally Open
NOCT	Nominal Operating Cell Temperature
NREL	National Renewable Energy Laboratory
PIC	Programmable Integrated Circuit
PV	Photovoltaic
PWBHPS	PV-Wind-BatteryHybrid Power System
PWM	Pulse Width Modulation
RE	Renewable Energy

SOC	State Of Charge
SPI	Systems Performance Indices
STC	Standard Test Condition
SZP	Simple Zones Probabilities
USM	University Science Malaysia
WDHS	Wind Diesel Hybrid System
WTG	Wind Turbine Generator

LIST OF SYMBOLS

A	Swept area of rotor blade
BC	Battery Capacity
C	Capacitor
C_i	Initial capital cost
D_r	Duty ratio
D_c	Maximum rotor at the center
D	Rotor diameter
$\frac{d}{d}$	Kinetic energy per unit time
e	Escalation rate
E_B	The quantities of battery bank
E_{GA}	Energy generated by PV and Wind generator
E_{Ch}	Charging battery
E_L	Load energy
E_O	Over load power
E_P	Annual energy generated by an independent solar system
E_P	Total of PWBHPS output energy
E_W	Wind energy
$E_{d \ h}$	Discharging battery
E_{d1}	Energy of dump load
F_S	Switching frequency
G	Insolation level
H	Height of the rotor
H_1	Hub height 1

H_2	Hub height 2
I	Interest rate
I_D	Diode current that flowing into p-n junction semiconductor
I_L	Inductor current
I_{L_r}	Root mean square inductor current
I_S	Short circuit current
I_S	Current at Standard Test Condition
I_{cha}	Charging time of the battery
I_m	Maximum power point current
I_n	PV array new current output
I_{ph}	Current source from solar cell
I_{r_si}	Battery rated source current
i_a	Adjusted interest rate
k	Weibull shape parameter
L	Inductor
LCC	Life cycle cost
M_p	Maximum module power
m_f	Mass flow
n	Life span of the system
P_L	Load power
P_O	Mechanical power generated by the rotor
P_R	Rate power
P_T	Wind turbine power output
P_N	Non-recurring cost to present worth
P_R	Recurring cost to present worth

P_s	System net worth in the final year of its life –cycle period
P_m	Mechanical power
P_n	PV array new power value
P	Payback Period
P	Number of years between two successive payments
R	Recurring rate
R_S	Constant temperature (=0.222)
R_S	Series resistance of the cell
R_{sh}	Shunt resistance of the cell
S	Salvage value
T_S	Temperature at Standard Test Condition
T_c	Cell temperature
T_m	Total module
T_s	Time period
T_a	Ambient temperature
$T_{a, ref}$	Reference ambient temperature
t_o	Time for switch on
V_0	Downstream wind velocity at the exit of the rotor blades
V_C	Cut in speed
V_{C0}	Cut off speed
V_O	Open circuit voltage of module
V_R	Rate wind speed
V_S	Voltage at Standard Test Condition
V_a	Air velocity
V_{i1}	Input voltage

V_m	Maximum power point voltage
V_n	New voltage output
V_{n_i}	PV array new voltage value
V_o	Output voltage
V_{o_r}	Root mean square capacitor voltage
V	Upstream wind velocity at the entrance of the rotor blades
V_1	Wind speed at H_1
V_2	Wind speed at H_2
ΔV_o	Peak to peak ripple voltage
α_S	Short circuit current temperature coefficient
α_S	Temperature coefficient of I_S
β_o	Open circuit voltage temperature coefficient
β_o	Temperature coefficients of V_o
η_B	Charge efficiency of battery bank
η_{i_i}	Efficiency of the inverter
	Exponent base on surface roughness and atmospheric
T_c	Temperature changes
I	PV array output current
I	Current change of PV array
V	Voltage changes of PV array
	Hourly self-discharge rate
ΔI_L	Peak to peak ripple current

**ANALISIS SISTEM KUASA HIBRID PV ANGIN BATERI (PWBHPS)
MENGUNAKAN KAEDAH KEBARANGKALIAN ZON MUDAH UNTUK
ISI RUMAH DI MALAYSIA**

ABSTRAK

Perkembangan *Sistem Kuasa Hibrid* telah menyumbang kepada penggunaan tenaga boleh diperbaharui sebagai sumber tenaga alternatif. Jumlah penggunaan tenaga boleh diperbaharui biasanya bergantung kepada jenis beban dan reka bentuk sistem. Tesis ini mencadangkan sistem kuasa hibrid yang akan menggunakan tenaga daripada solar dan angin sebagai sumber utama. Konfigurasi sistem kuasa hibrid yang telah dimodelkan terdiri daripada tenaga solar, angin dan bateri dan ia disambung secara selari dengan grid. Satu teknik baru yang dikenali sebagai *Kaedah Kebarangkalian Zon Mudah* telah dilaksanakan untuk mengoptimumkan prestasi sistem secara menyeluruh. Profil beban yang digunakan dalam kajian ini mempunyai beban puncak pada waktu sinaran matahari. Data tenaga angin dan solar yang dikumpul dianalisis menggunakan Microsoft Excel untuk mendapatkan jumlah kuasa keluaran bagi kebarangkalian kawasan. Lokasi yang bersesuaian telah dipilih sebagai kajian asas kerana ketersediaan data dan potensi untuk memasang sistem hibrid di Malaysia, di mana ia telah direkodkan untuk keamatan sinaran solar dan purata kelajuan angin didapati berada pada 5.5kWh /m²/hari dan 3m/s masing-masing. Keputusan praktikal adalah berdasarkan kepada 1.4 kW sistem tenaga solar, 2kW turbin angin dan 10 buah bateri 18Ah. Berdasarkan data kelajuan angin dan sinaran solar maka kuasa purata yang boleh dijana adalah hanya 30% daripada kapasiti keseluruhan sistem. Oleh itu, jumlah maksimum tenaga tahunan yang dihasilkan adalah 4013 kWh dan untuk sepanjang 30 tahun dijangka dapat menjana kira-kira 123090 kWh. Hasil purata keluaran analisis kuasa sistem PWBHPS dengan menggunakan kaedah kebarangkalian

zon yang mudah, boleh membekalkan permintaan beban sebanyak 66.65%, manakala tanpa menggunakan kaedah kebarangkalian kawasan yang mudah iaitu 53.6% di semua lokasi terpilih. Keputusan menunjukkan bahawa PWBHPS berpotensi paling tinggi diperolehi di Mersing, Johor (iaitu 100%). Di samping itu, PWBHPS boleh digunakan silih berganti secara automatik bersama sistem grid untuk menyediakan permintaan beban. Analisis ekonomi menunjukkan bahawa kos asas bagi 2 kW PWBHPS ialah RM 20,951, dan tempoh bayaran balik adalah lebih kurang 19 tahun, iaitu kos seunit ialah 27 sen per kWh.

**ANALYSIS OF PV WIND BATTERY HYBRID POWER SYSTEM (PWBHPS)
USING SIMPLE ZONE PROBABILITIES (SZP) METHOD FOR
HOUSEHOLD IN MALAYSIA**

ABSTRACT

The development of Hybrid Power System (HPS) had contributed to the utilization of Renewable Energy (RE) power as an alternative power source. The total usage of RE is normally depend on the type of load and the system design. This thesis proposed the PV Wind Battery Hybrid Power System (PWBHPS) that will utilize energy from solar and wind as a main source. The hybrid configuration that was modeled consists of PV, Wind and Battery and it was connected in parallel with the grid. A new technique which is known as Simple Zone Probabilities (SZP) had been implemented to optimize the overall system performance. The load profile which is employed in this study has a peak load during sun hours (e.g. at noon). The collected daily data of wind and solar was arranged through Microsoft Excel to determine the total output power for zoning probabilities. The suitable locations in Malaysia were selected as a base study due to data availability and the potential to install the hybrid system. It has been recorded that solar radiation intensity and average wind speed in Malaysia are found to be 5.5 kWh/m²/day and 3m/s, respectively. The practical results are based on 1.4 kW photovoltaic, 2 kW wind turbine and 10 batteries of 18Ah where the average power that can be generated is nearly 30% of the total system capacity. The results show that the total annual energy maximum generated is 4013 kWh and for 30 years life span is expected to be 123090 kWh. Results from the developed PWBHPS show the average output power using SZP can supplying a load of 66.65 %, while without SZP of 53.6% at the selected locations. The results show that the highest potential energy hybrid was obtained at Mersing, Johor (100%). This thesis also

describes that the PWBHPS can be used interchangeably automatically with the grid in serving the load. The economic analysis shows that the initial cost of the 2 kW PWBHPS is RM 20,951 and the payback period is calculated to be nearly 19 years, where the cost is 27 cents per kWh.